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STUDIES ON MARINE DIATOMS AND DINOFLAGELLATES CAUGHT WITH THE KOFOID BUCKET IN 1923

BY

HENRY P. DORMAN

BULLETIN OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY
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of the University of California
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INTRODUCTION

The purpose of this paper is to add to the evidence on the vertical distribution of diatoms and dinoflagellates from the surface of the sea to depths of ten, twenty, and forty meters. This is the third paper published on material collected at stations 1 and 2, ten and five miles, respectively, seaward from the pier of the Scripps Institution of Oceanography.

Collections recorded in this investigation were made between May 23 and June 15, 1923, at both stations, from the boat HE, usually between 7 A.M. and 2 P.M. The Kofoid bucket, which holds approximately five gallons of water, was employed for making subsurface collections, and surface collections, made with a pail, conformed to this procedure (Allen, 1923*a*). Filtration was made through No. 25 silk bolting cloth and the concentrated microplankton was preserved in 5 to 15 per cent formaldehyde.

The methods employed in counting the numbers of colonies and the total numbers of cells per liter are described in Allen's paper (1921). Additional information may be found in the 1922*a* paper of the same author, to whom the writer expresses his thanks for guidance and suggestions.

DISCUSSION

Considering the collections as a whole, the average number of diatoms per liter exceeded the average number of dinoflagellates per liter at the surface and at the three subsurface depths.

TABLE 1

AVERAGE NUMBER PER LITER OF DIATOMS AND DINOFLAGELLATES IN SAMPLES OF SEA WATER FROM THE SURFACE AND THREE DEPTHS AT STATIONS 1 AND 2, MAY–JUNE, 1923

	Surface	10 meters	20 meters	40 meters
Station 1:				
Number of catches	13	8	7	8
Average per liter:				
Diatoms	198,727	214,164	593,131	115,957
Dinoflagellates	6,559	475	539	288
Station 2:				
Number of catches	13	7	7	7
Average per liter:				
Diatoms	120,164	184,511	869,187	55,793
Dinoflagellates	11,804	6,229	762	188

Data are given in table 3 for eleven other surface catches made at various locations near stations 1 and 2, but the discussion is confined to the two stations.

The above results agree with those obtained by Allen in 1921 and 1922.* The number of dinoflagellates in a given collection exceeded the number of diatoms in only one catch at regular stations, viz., a catch made at 9:20 A.M., May 29, station 2, surface, which yielded 22,588 diatom cells and 22,934 dinoflagellates, a difference of little significance.

A comparison of the number of cells collected at the two stations indicates that the largest number of diatoms at each station occurred at depths of ten and twenty meters, the twenty-meter region being the most productive (tables 1 and 4). The surface ranked third in production and the forty-meter region last. This is not entirely true in the case of dinoflagellates, and an analysis of the results will be made; for no general statement will apply. The surface region was most productive at both stations 1 and 2, but the results of counts

* It should be stated that count records were misplaced before this paper was completed, and the average number of dinoflagellates per liter is closely approximate.

from the three subsurface depths indicate that, at station 1, the ten-meter region is superior in production to the same depth at station 2. The differences in production between the twenty- and forty-meter regions at the two stations are negligible. These results coincide with Allen's tables of investigation of 1921 and 1922 (Allen, 1923*b*, 1923*c*).

Considering the catches at each station as wholes, station 2 was slightly more productive than station 1 (table 1). However, the

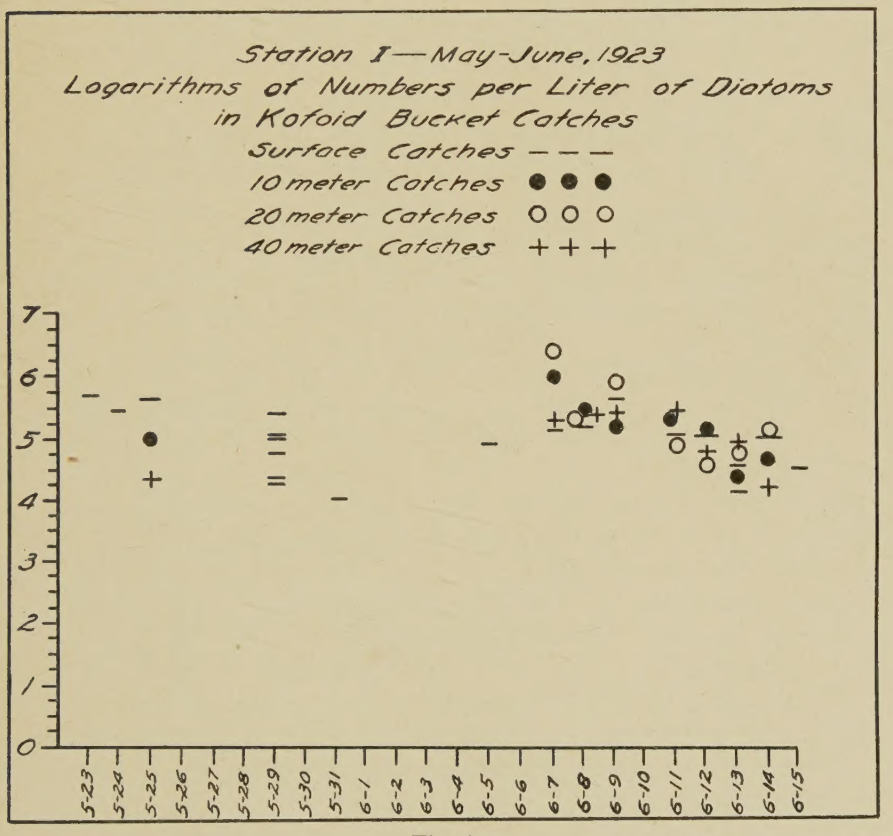

Fig. 1

(Two or more entries on a single date indicate catches made in the same general locality while drifting.)

number of diatoms produced at station 1, surface, exceeded the corresponding number at station 2; the reverse was true of the numbers of dinoflagellates for the same region. The latter statement concerning the number of dinoflagellates at stations 1 and 2, surface, also applies to the three depths at the two stations, except in the twenty-meter region; production was greater at station 2, surface, than at station 1, surface (table 1). The numbers of dinoflagellates at the

TABLE 2

TOTAL NUMBER OF CELLS PER LITER, TEMPERATURE, SALINITY, AND pH AT THE SURFACE, STATIONS 1 AND 2

Date	Station 1, Surface					Station 2, Surface				
	Hour	Number cells per liter	Temperature	Salinity 0/00	pH	Hour	Number cells per liter	Temperature	Salinity 0/00	pH
May 23	11:20 A.M.	509,243	18.65	33.57	8.42	12:20 P.M.	101,020	19.00	33.60	8.45
24	10:45	300,139	18.65	33.54	8.43	1:00	123,960	19.00	33.57	8.47
25	10:15	497,823	19.05	33.57	8.47	1:45	42,378	19.35	33.58	8.47
29	9:20	44,982	18.40	33.57	8.47					
31	9:07	35,156	17.80	33.62	8.45	8:27 A.M.	56,332	17.40	33.61	8.45
June 4						11:05	37,055	18.48	33.58	8.53
5	11:13	77,256	18.52	33.58	8.44	12:15 P.M.	58,841	18.58	33.61	8.43
7	11:15	132,424	17.55	33.60	8.48	11:48 A.M.	278,952	17.55	33.60	8.48
8	9:50	140,456	18.14	33.46	8.48	12:23 P.M.	376,712	18.49	33.62	8.48
9	8:43	376,210	18.19	33.97	8.43	11:25 A.M.	108,464	18.82	33.67	8.46
11	8:04	126,388	17.94	33.58	8.47	11:05	19,900	18.80	33.68	8.47
12	10:00	107,908	17.31	33.64	8.48	11:45	130,814	18.38	33.64	8.52
13	7:17	148,000	17.26	33.68	8.39	9:00	134,668	18.99	33.68	8.45
	7:25	37,400	17.26	33.68	8.39					
14	8:18	101,056	17.37	33.64	8.43	9:50	39,000	18.04	33.64	8.45
15	9:55	31,400	17.60	33.67	8.41	11:35	91,088	18.33	33.69	8.49

twenty- and forty-meter regions were small compared with other results and cannot be regarded as significant.

It is impracticable to present a complete count record of each species of diatom found in catches at various depths at the two stations, but the more prominent genera and some of the commoner species will be considered, especially in regard to range, both as to station and as to depth.

DISTRIBUTION

Surface

Records show that eighteen different genera and thirty-nine different species were collected at the surface level, station 1. Of these genera and species, all except *Chaetoceras didymum* Ehr., *C. neapolitanum* Schröder, *C. peruvianum* Btw., *C. simile* Cleve, *Navicula membranacea* Cleve, and *Skeletonema costatum* (Grev.) were also found at the surface, station 2. There is a slightly greater variety of species at the station nearer to shore. The genus *Chaetoceras* was found to be by far the most abaundant of the genera collected at the two stations, if we consider them separately or as a whole, both from the point of view of the number of colonies and the number of cells. The largest number of cells recorded in a single catch for a genus was in *Chaetoceras* sp., the catch-all group, used where specific identification is impracticable. A catch made at station 1 on May 23, at 11:20 A.M., yielded 309,256 cells in 67,983 colonies per liter. *N. seriata* Cleve was second largest in numbers, a catch made at station 1, on June 9, at 8:43 A.M., yielding 126,096 cells in 71,040 colonies.

At station 2, *Nitzschia seriata* Cleve occurred consistently and abundantly and ranked first in numbers of cells and colonies. The largest single catch was made on June 8, at 12:23 P.M., and this catch yielded 285,048 cells in 66,600 colonies per liter. *Chaetoceras compressum* Laud. and *C. decipiens* Cleve ranked second and third in numbers. *Rhizosolenia styliformis* Btw., which does not occur in colonies, was consistent in occurrence throughout the period, the number of cells reaching 21,756 per liter on June 15. The smallest single catch, made on May 25, was 154 cells per liter.

Ten Meters

Twelve genera and twenty-six species were collected at this depth at station 1, and nine genera and eighteen species were collected at the same depth at station 2. The genera and species of station 1 include *Cerataulina bergonii* Perag., *Chaetoceras compressum* Laud.,

C. curvisetum Cleve, *C. pendulum* Karsten, *C. scolopendra* Cleve, *C. simile* Cleve, *Hemiaulus hauckii* Grün, *Licmophora lyngbyei* (Kütz.), and *Rhizosolenia alata* Btw., none of which species were recorded for station 2. On the other hand, all genera and species

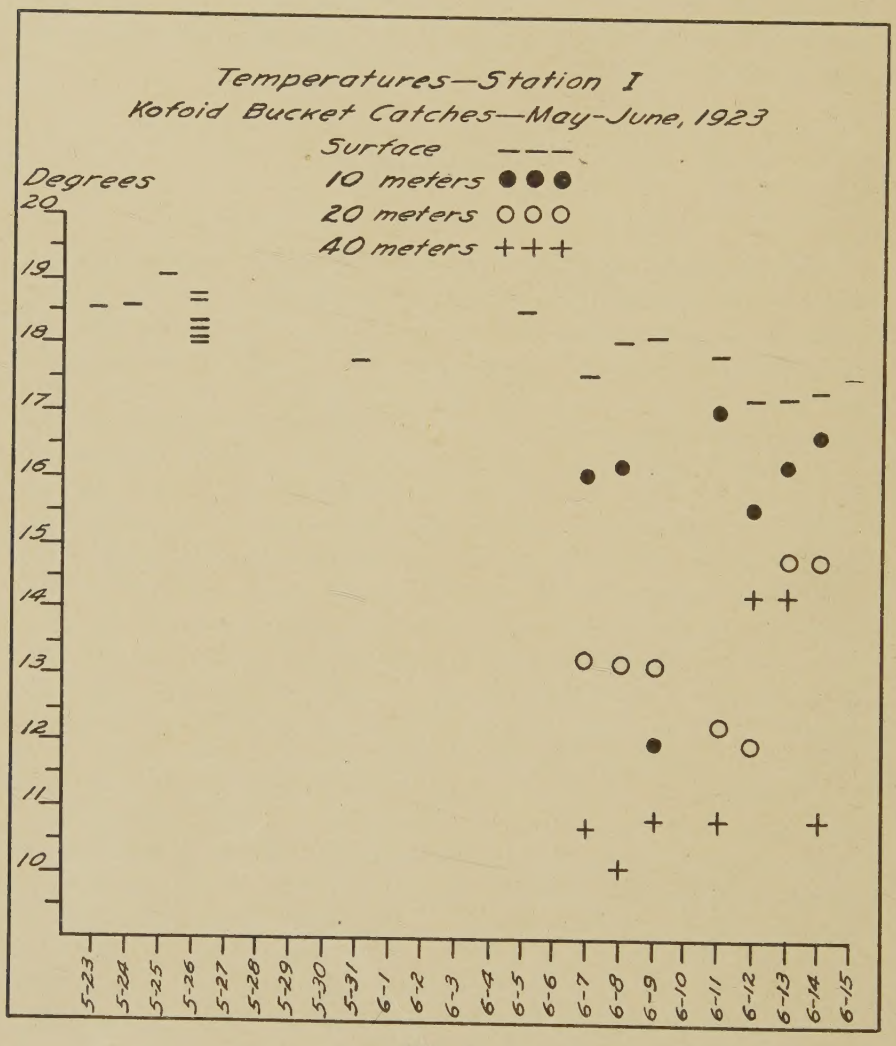

Fig. 2

(Two or more entries on a single date indicate catches made in the same general locality while drifting.)

found at station 2 were found at station 1. It should be stated that the occurrences of these species at station 1 were rare compared with the predominant species; e.g., *R. alata* Btw. was collected on only two days, May 25 and June 7, the catches yielding 445 and 888 cells per liter, respectively. Other species of this group were even more rare.

At station 1, *Nitzschia seriata* Cleve was for this period by far the most abundant in numbers of cells and colonies. The largest single catch was recorded on June 7, at 11:12 A.M., and yielded 312,576 cells in 133,128 colonies per liter. *Chaetoceras criophilum volans* (Schütt), a non-colonial form, was second in abundance, with the largest single catch yielding 137,640 cells per liter, recorded on June 7, at 11:12 A.M. *C. compressum* Laud. was third in abundance; the largest single catch was recorded on June 8, at 9:55 A.M., and was 86,124 cells from 17,760 colonies per liter.

TABLE 3

TOTAL NUMBER OF CELLS PER LITER, TEMPERATURE, SALINITY, AND pH AT THE SURFACE, COLLECTIONS MADE ONE TO TWENTY MILES FROM STATIONS 1 AND 2

Date	Hour	Number cells per liter	Temperature	Salinity 0/00	pH	Position
May 29	10:36 A.M.	129,213	18.40	33.57	8.48	3 mi. W. Sta. 2.
	10:53	64,523	18.68	33.58	8.49	2 mi. W. Sta. 2.
	11:00	29,720	18.72	33.55	8.45	1 mi. W. Sta. 2.
	11:09	57,189	18.64	33.57	8.46	1½ mi. W. Sta. 2.
	11:16	60,520	18.38	33.57	8.48	1 mi. E. Sta. 2.
	11:25	256,938	18.28	33.57	8.47	2 mi. E. Sta. 2.
	11:33	97,790	18.11	33.60	8.48	3 mi. E. Sta. 2.
May 31	9:53	230,824	18.17	33.67	8.45	5 mi. S.E. Sta. 1.
	10:34	55,308	18.40	33.64	8.45	10 mi. S.E. Sta. 1.
	11:16	19,610	18.43	33.67	8.45	15 mi. S.E. Sta. 1.
	11:58	14,338	18.18	33.74	8.40	20 mi. S.E. Sta. 1.

At station 2, *Nitzschia seriata* Cleve was superior in numbers of cells; the largest single catch was recorded on June 11, at 11:05 A.M., and yielded 227,328 cells from 40,848 colonies per liter. *C. compressum* Laud. and *N. seriata* Cleve were present in all catches at the ten-meter depth, but the total number of cells of *C. compressum* Cleve for this period was not so large as that of *N. seriata* Cleve. The above-mentioned catch yielded 167,732 cells from 31,070 colonies per liter, the largest number recorded for this species. *C. criophilum volans* (Schütt) was consistent and abundant in occurrence, ranking third, and *C. decipiens* Cleve came fourth. *Rhizosolenia styliformis* Btw. and *Thalassiothrix acuta* Karst., both non-colonial forms, were present in every catch recorded for this period. These two species should be considered as consistent but not regular in occurrence. The abundance of *R. styliformis* Btw. varied from 19,092 to 2,400 cells per liter, and of *T. acuta* Karst. from 11,100 to 600 cells per liter.

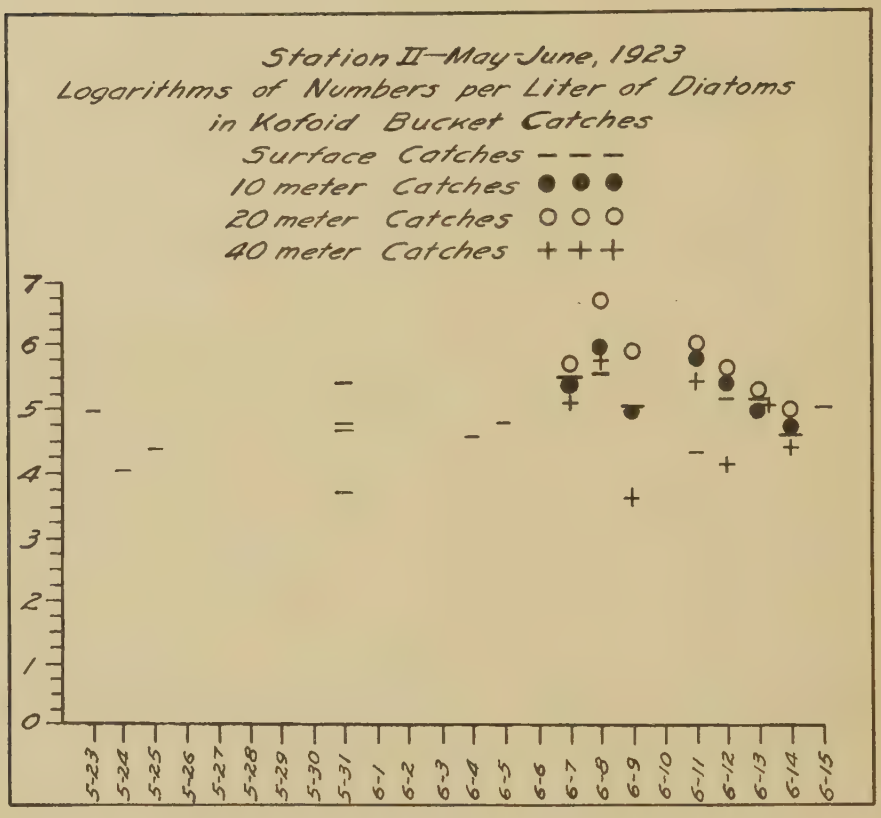

Fig. 3

(Two or more entries on a single date indicate catches made in the same general locality while drifting.)

Twenty Meters

At station 1, twelve genera and twenty-five species were recorded for this depth, while at station 2 thirteen genera and twenty-four species were found. *Actinoptychus undulatus* Bail., *Chaetoceras simile* Cleve, *Rhizosolenia alata* Btw., and *Thalassiothrix frauenfeldii* (Grün.) were included in the catches at station 1 but not in those at station 2. *Nitzschia closterium* W. Sm., *Plantoniella sol* (Wallich), and *Skeletonema costatum* (Grev.) were recorded from the collections at station 2, but not from those of station 1. Considering the first case, it is noteworthy that *A. undulatus* Bail. was recorded only in the catch made on June 7, at 11:05 A.M., yielding 1,998 cells per liter. Likewise, *C. simile* Cleve and *T. frauenfeldii* (Grün.) were recorded for only one day, while *R. alata* Btw. yielded 3,330 and 600 cells per liter on June 7, at 11:05 A.M., and June 13, at 7:13 A.M.,

TABLE 4

TOTAL NUMBER OF CELLS PER LITER, TEMPERATURE, SALINITY, AND pH AT TEN, TWENTY, AND FORTY METERS, STATIONS 1 AND 2

Date	Hour	Number cells per liter	Temperature	Salinity 0/00	pH
Station 1, 10 meters					
May 25	9:20 A.M.	96,890		33.46	8.42
June 7	11:12	824,829	16.10	33.54	8.49
8	9:55	273,016	16.21	33.55	8.49
9	9:42	141,584	12.00	33.61	8.30
11	10:00	187,398	17.04	33.61	8.47
12	10:13	124,200	15.62	33.53	8.49
13	7:20	22,000	16.26	33.62	8.47
14	8:15	47,232	16.71	33.62	8.43
Station I, 20 meters					
June 7	11:05 A.M.	2,469,330	13.27	33.53	8.41
8	9:48	240,276	13.25	33.50	8.38
9	9:30	709,280	13.25	33.50	8.38
11	9:52	70,028	12.00	33.61	8.30
12	10:04	35,600	12.33	33.53	8.40
13	7:13	40,800	14.87	33.51	8.47
14	8:02	103,280	14.87	33.51	8.47
Station I, 40 meters					
May 25	9:40 A.M.	23,430	19.05		
June 7	11:00	170,151	10.82	33.54	8.17
8	9:38	165,346	10.17	33.67	8.05
9	9:18	235,664	10.97	33.54	8.17
11	9:45	163,558	10.97	33.54	8.17
12	9:53	56,000	14.35	33.49	8.26
13	7:05	68,408	14.35	33.49	8.26
14	7:45	47,400	10.97	33.54	8.17

Hour	Number cells per liter	Temperature	Salinity 0/00	pH
Station 2, 10 meters				
12:12 P.M.	305,836	16.10	33.54	8.49
12:18 P.M.	66,844	16.04	33.58	8.49
12:41 P.M.	100,218	16.04	33.58	8.49
11:05 A.M.	514,700	15.10	33.53	8.43
11:40	226,332	15.62	33.53	8.49
8:50	81,644	17.04	33.61	8.47
9:34	39,600	16.71	33.62	8.43
Station II, 20 meters				
12:07 P.M.	427,341	13.27	33.53	8.41
12:11	3,570,977	11.54	33.53	8.31
12:32	696,136	13.25	33.50	8.38
11:00 A.M.	813,660	12.00	33.61	8.30
11:33 A.M.	361,393	12.33	33.53	8.40
8:59	169,324	14.87	33.51	8.47
9:24	50,800	13.36	33.51	8.39
Station II, 40 meters				
11:55 A.M.	122,988	10.82	33.54	8.17
12:05 P.M.	46,804	10.20	33.58	8.13
12:13	3,800	10.20	33.58	8.13
10:45 A.M.	71,000	10.26	33.60	8.08
11:24	11,800	10.24	33.64	8.14
8:31	112,068	14.35	33.49	8.26
9:17	23,400	11.20	33.53	8.20

respectively. *N. closterium* W. Sm., *P. sol* (Wallich), and *S. costatum* (Grev.), found at station 2, but not at station 1, occurred on three, one, and one days, respectively. *N. closterium* W. Sm., the most abundant of the three, yielded 4,000, 200, and 600 cells per liter in

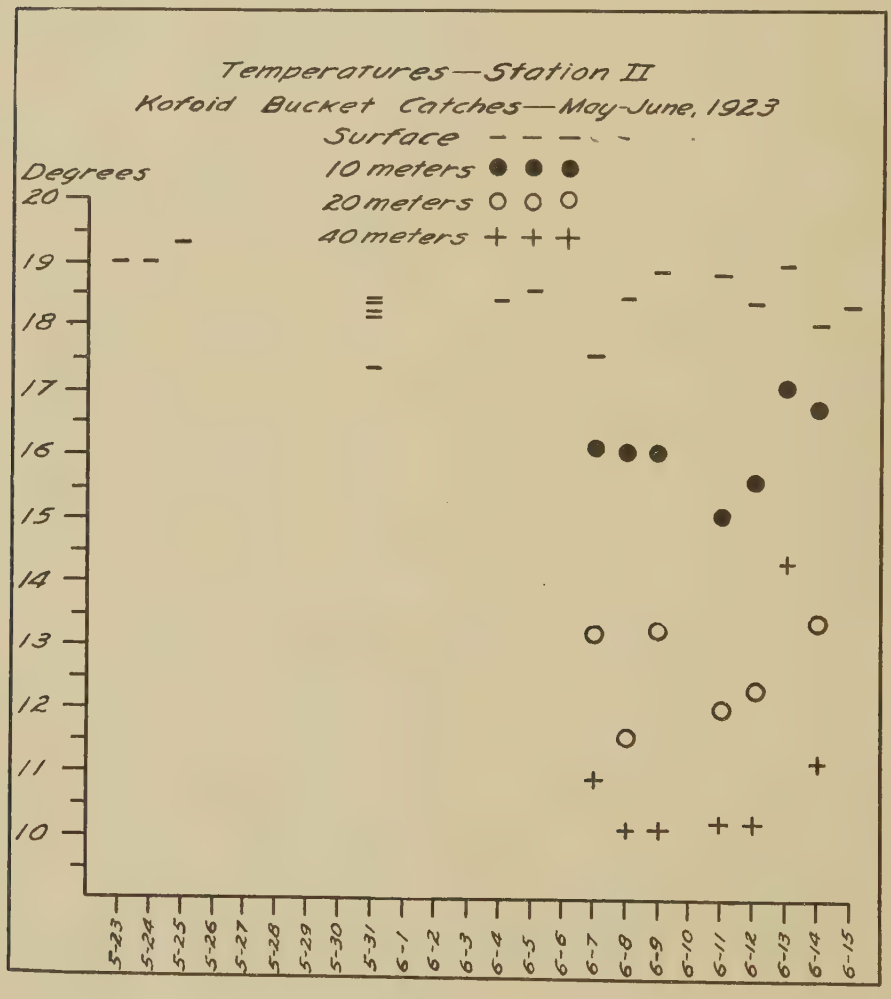

Fig. 4

(Two or more entries on a single date indicate catches made in the same general locality while drifting.)

catches made on June 12, at 11:33 A.M., June 13, at 8:59 A.M., and June 14, at 9:24 A.M., respectively. *P. sol* (Wallich) yielded 400 cells per liter in the catch made on June 12, at 11:33 A.M., while *S. costatum* (Grev.), recorded from the catch made on June 7, at 12:07 P.M., yielded 1,110 cells from 111 colonies per liter.

At station 1, *Nitzschia seriata* Cleve produced during this period more cells per liter than any other one species. The catch made on June 7, at 11:05 A.M., was especially abundant in this species, 270,180 colonies yielding 1,134,040 cells per liter. The catches made on June 12, at 10:04 A.M., and June 13, at 7:13 A.M. (4,200 and 2,400 cells, respectively), were practically negligible for this species, when it is considered that previous catches averaged more than two hundred thousand cells per liter. The catch made on June 14, at 8:02 A.M., yielded none of this species. *C. compressum* Laud., with an average of 75,000 cells per liter for eight catches, ranked second in production. In the catch made on June 7, at 11:05 A.M., *C. criophilum volans* (Schütt) showed 462,150 cells per liter. *C. decipiens* Cleve also produced abundantly, especially from June 7 until June 11. *Rhizosolenia styliformis* Btw. produced consistently, but throughout the period the quantity varied from 7,600 to 600 per liter.

At station 2, *N. seriata* Cleve was exceedingly abundant throughout the entire period, the height of its production being reached on June 8, at 12:11 P.M., when 3,562,977 cells from 663,267 colonies per liter were recorded. *Chaetoceras compressum* Laud. was second in production, and reached its height on June 11, at 11 A.M., with 101,132 cells from 9,768 colonies per liter. *C. criophilum volans* (Schütt) was also consistent and regular in production. *Dactyliosolen tenuis* (Cleve), *R. styliformis* Btw., and *Thalassiothrix acuta* Karst., and *T. nitzschioides* Grün. produced consistently.

Forty Meters

Sixteen genera and thirty-one species were recorded for station 1 at this depth and ten genera and seventeen species for station 2. The genera and species found at station 1 and missing at station 2 were: *Actinoptychus splendens* (Ehr.), *Asteromphalus heptactis* (Bréb.); *Bacteriastrum elongatum* Cleve, *Cerataulina bergonii* Perag., *Chaetoceras curvisetum* Cleve, *C. danicum* Cleve, *C. debile* Cleve, *C. didymum* Ehr., *C. neapolitanum* Schröder, *C. pendulum* Karsten, *Leptocylindricus danicus* (Schütt), *Planktoniella sol* (Wallich), *Pleurosigma* sp., and *Thalassiosira hyalina* (Grün.). Only two of these forms were in more than one catch: *C. debile* Cleve and *L. danicus* Schütt, and none of them exceeded 900 cells per liter, except *C. debile* Cleve (3,828 cells) and *T. hyalina* (Grün.) (4,000 cells). Two species found at station 2 were not recorded for station 1: *Lauderia borealis* Gran was collected on June 7 and 13 (220 and 400 cells, respectively), and *Navicula membranacea* Cleve on June 9, 1,200 cells per liter.

At station 1, *Nitzschia seriata* Cleve averaged more than 30,000 cells in each collection from May 25 until June 14; *Chaetoceras compressum* Laud. produced about the same quantity as *N. seriata* Cleve; *C. criophilum volans* (Schütt) and *C. decipiens* Cleve also produced steadily and regularly. *Rhizosolenia styliformis* Btw. and *Thalassiothrix nitzschioides* Grün. averaged more than 1,200 and 4,000 cells per liter, respectively. At station 2, *N. seriata* Cleve, *C. compressum* Cleve, and *C. criophilum volans* (Schütt) were the most numerous in collections for the same period, but production as a whole was considerably less than at station 1.

SUMMARY

1. The quantity production of diatoms and dinoflagellates at distances of five and ten miles from shore in the San Diego region seems to be of the same order of magnitude at a given station and at certain depths from year to year. Moreover, the occurrence of diatoms and of dinoflagellates at a given station and at a given depth for three consecutive years has exceeded the occurrence of the same organisms at another given station and the corresponding depth.

2. With three exceptions, all catches at all levels were more abundant in diatoms than in dinoflagellates.

3. Diatoms were more abundant at both stations at depths of ten and twenty meters than at any others, the twenty-meter depth being the most productive. The work does not indicate that this is true of dinoflagellates, but each station and each depth must be considered as a separate case.

4. In the aggregate, the nearest-to-shore station (2) was slightly more productive than the ten-mile-off-shore station (1). However, this general condition does not obtain for each station at each depth. Each depth at one station should be compared with the corresponding depth at the other station. When the eight pairs of corresponding figures (four depths and two types of organisms) are compared for the two stations, each station shows preponderance in an equal number of cases (table 1).

5. A greater variety of genera and species was collected from the five-mile station than from the one ten miles out. Some forms found at station 1 were absent from station 2, and vice versa, but there were more instances of such exclusive occurrence at station 2.

6. The range of some genera and some species at both stations is from the surface to the forty-meter level, but there is a decided decrease in the variety of forms from the surface downward to the forty-meter level.

7. Coincident results for the past three years indicate that the methods of procedure employed are sound and well adapted to this type of investigation.

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